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# A Novel Traffic Grooming Scheme for Nonlinear Elastic Optical Network

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**Abstract** *We propose a traffic grooming enabled nonlinearity-aware resource allocation scheme for elastic optical networks. The results show that proposed approach outperforms the benchmarks by providing higher service acceptance ratio and up to 50% reduction in number of transceivers.*

## Introduction

The significant challenge faced by service providers is to support exponential growth of dynamic traffic towards access, metro as well as core networks<sup>1</sup>. Traditional optical core network is not optimized for supporting dynamic services with flexible bandwidth requirements. Elastic optical networks<sup>2</sup> (EON) based on coherent detection is a promising technology to meet the emerging heterogeneous traffic demands by enabling grid-less switching and bandwidth adaptable transceivers. In addition, by using coherent detection in EON, the dispersions are compensated at the receivers by digital signal processing technique. However, nonlinear impairments (NLI) are difficult to mitigate using feasible approaches. Therefore, NLI become one of major penalties which affect the performance of EON. Nonlinearity-aware resource allocation scheme<sup>3</sup> use Gaussian noise (GN) model<sup>4</sup> as NLI model to minimize the maximum subcarrier index. However, the optimization has only been studied for static traffic matrix with large bandwidth requirements.

In this paper, we propose a new nonlinearity-aware routing, modulation format and spectrum assignment (RMSA) scheme in EON. The proposed approach combines traffic grooming which has been well adopted in conventional WDM system<sup>5</sup> to improve the network efficiency and spectrum utilization. We further compared the proposed approach with two benchmark methods. Through extensive simulation studies, we demonstrate that proposed scheme can reduce both service blocking ratio and the number of transceivers consumed.

## Physical Layer Information Model

In this work, nonlinear impairments and amplified spontaneous emission (ASE) are considered as the dominant penalties during transmission. The symbol signal-to-noise ratio (SNR) at the receiver can be described as:

$$SNR_{Rx} = G_{sig} / (G_{ASE} + G_{NLI}) \quad (1)$$

where  $G_{sig}$ ,  $G_{ASE}$  and  $G_{NLI}$  are the power spectral density (PSD) of signal, ASE and NLI

respectively. The PSD equation of ASE can be written as:

$$G_{ASE} = 10^{\frac{NF}{10}} \cdot h\nu \sum_n (10^{\frac{A_n}{10}} - 1) \quad (2)$$

where  $NF$  is the noise figure of the erbium doped fiber amplifiers (EDFA),  $h$  is Planck's constant and  $\nu$  is signal central frequency.  $A_n$  represents the signal power loss in dB including span loss and optical node insertion loss. We use GN model<sup>4</sup> to obtain the channel NLI information. When network blocking occurs due to lack of spectrum resources, the network can be regarded as being highly loaded. In this case, NLI PSD values are closed to the case where link is 100% occupied. Hence, we calculate the NLI PSD of each spectrum slot's central frequency assuming full channel loading. For a connection occupying multiple spectrum slots, the overall average NLI PSD can be written as:

$$G_{NLI} = \sum_k^{NS} \sum_{i=1}^M G_{NLI}^i / M \quad (3)$$

where the  $i$  is the spectrum slot index,  $M$  and  $NS$  is the spectrum slots number and total span number for the connection. To ensure the transmission quality, the SNR of each connection must be greater or equal to the SNR threshold of the assigned modulation format. The SNR threshold in this work is set to achieve  $4 \times 10^{-3}$  pre-FEC bit error rate. The available modulation format set is chosen from DP-BPSK, DP-QPSK, QP-8QAM, DP-16QAM and DP-32QAM. We follow the same network assumption in <sup>6</sup> for this work.

## Algorithm Description

We assume that each request  $R$  consists of bi-direction traffic demand  $r$  from source  $s$  to destination  $d$ , sequentially loaded into the network. A least congested path  $P$  is calculated. According to the path  $P$ , average link loading condition  $lc$  is written as:

$$lc = \sum_{j=1}^L W_j / LN \quad (4)$$

where  $LN$  is the link number of path  $P$ . The algorithm operates strategy 1 when the selected path is less congested ( $lc$  less than the setting

threshold  $sthd$ ). Otherwise it performs strategy 2.

#### Proposed Algorithm:

<b>Input :</b>	Request $R_i$
<b>Output :</b>	RMSA solution for the $r_i$
1.	Find a least congested path $P_i$ for $r_i$ from $s_i$ to $d_i$ ;
2.	Calculated average link loading condition $lc_i$ given in eq.4 along the path $P_i$ ;
3.	<b>if</b> $lc_i$ is less than setting threshold $sthd$
4.	Run strategy 1
5.	<b>else</b> strategy 2
6.	<b>end if</b>

Strategy 1 first finds spectrum slots  $S$  for the connection request  $R$  when assigning modulation format  $MF$  (from DP-BPSK to DP-32QAM). If the resources are available, then the ASE and NLI PSD are calculated. We compute the SNR to check whether it satisfies the SNR requirement for  $MF$ . The service request is accepted, the maximum capacity and highest available modulation format of the new lightpath are recorded when the it meets SNR requirement. In case of no contiguous spectrum resources available or quality of transmission (QoT) constraint cannot be satisfied, the existing lightpaths of the same source/destination pair will be checked. If any lightpath has the sufficient SNR margin for modulation format upgradation to accommodate the new traffic request, the service request will be accepted and new traffic will be groomed with existing lightpath.

#### Strategy 1

1.	<b>for</b> $MF_i = \text{DP-BPSK to DP-64QAM}$
2.	Calculate required number of spectrum resources $sr_i$ for $r_i$ for $MF_i$ ;
3.	Find $sr_i$ free contiguous spectrum resources using first-fit assignment;
4.	<b>if</b> found
5.	Denote slots as $S_i = [s_i, \dots, s_i + sr_i - 1]$ ;
6.	Calculate the NLI PSD based on $S_i$ occupied according to eq.3
7.	Calculate $SNR_i$ given in eq. 1
8.	<b>if</b> $SNR_i$ is greater than $SNR$ threshold for $MF_i$ .
9.	Request accepted, setup a newlight path for $r_i$ ;
10.	Record the highest order modulation format and maximum capacity of the new lightpath;
11.	<b>end if</b>
12.	<b>end if</b>
13.	<b>end for</b>
14.	<b>if</b> no spectrum resources available or QoT fails
15.	<b>if</b> any active lightpath between $s_i$ and $d_i$ exists
16.	Denote available lightpath as $ALP_i = [lp_1, \dots, lp_m]$ ;
17.	<b>for</b> $j = 1:m$
18.	<b>if</b> $lp_j$ maximum capacity can accommodate $r_i$
19.	Request accepted, Upgrade $lp_j$ modulation format, update $lp_j$ information;
20.	Break <b>for</b> ;
21.	<b>end if</b>
22.	<b>end for</b>

23. **end if**  
24. **end if**

Strategy 2 operates the opposite way as strategy 1 does. It first examines whether any active lightpath of same source/destination pair has the potential capacity to groom the new traffic request. When traffic grooming is not feasible, it finds a new lightpath to serve the new service.

#### Strategy 2

1.	<b>if</b> any active lightpath from $s_i$ to $d_i$ exists
2.	Repeat step 15 to 23 from Strategy1
3.	<b>else</b>
4.	Repeat step 1 to 13 from Strategy 1
5.	<b>end if</b>

### Simulation Environment and Results Discussion

We consider network operates in C-band with 193.6 THz as central frequency. The 5 THz bandwidth are divided into 400 spectrum slots in a fibre with 12.5 GHz each. The ROADM is assumed with 7.5 dB insertion loss and noise figure of EDFA is set to be 5 dB. We use NSFNET topology with 14 nodes and 21 links deploying single mode fibre for evaluation. The fibre parameters are summarized in the table below:

**Tab. 1:** Link parameters

Parameters	Value
fibre loss coefficient	0.22 dB/km
fibre nonlinear coefficient	$1.3 W^{-1} km^{-1}$
chromatic dispersion coefficient	$16.7 ps \cdot nm^{-1} km^{-1}$
Span length	80km

Bi-direction 100 Gbps requests between uniformly selected pairs of source and destination including FEC overhead are evaluated in our work. We randomly generate 3000 service requests to be sequentially provisioned into the network. This process has been repeated 1000 times to build statistical results. To make fair comparison, the same set of traffic requests are repeated for all the scenarios. The results of proposed algorithm were compared with two benchmarks. The benchmark 1 can be summarized as a RMSA scheme<sup>7</sup> utilizing least congested routing and first spectrum assignment without traffic grooming and the benchmark 2 is a traffic grooming enabled scheme<sup>8</sup>. We set  $sthd$  factor to be 0.4 for the proposed algorithm.

Fig. 1 depicts the average blocking probability of proposed algorithm and two benchmarks against the number of requests for PSD being 19 mW/THz. It indicates the proposed algorithm has better service acceptance ratio than two benchmarks. Approximate 100 and 300 more 100G requests can be achieved respectively when adopting proposed algorithm than 2 benchmarks.

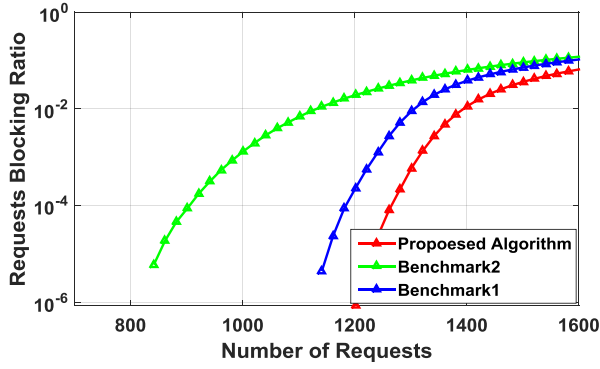


Fig. 1: Service blocking ratio versus number of requests.

Fig. 2 shows the average number of transceivers deployed for each scheme over the increasing network traffic load. Proposed algorithm can offer up to 50% number of transceivers saving over benchmark 1. The numbers of transceivers in both two benchmarks appear being linear with network load. However, benchmark 2 performs to combine several connection requests into one lightpath, thereby significantly reduction of transceivers number can be achieved.

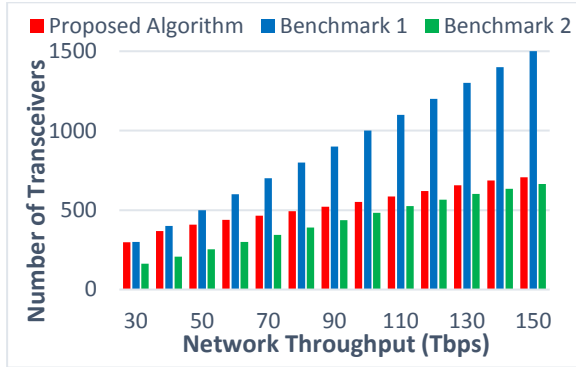


Fig. 2: Number of transceivers versus increasing network load (PSD: 19 mW/THz).

As the network is in low loading state, the number of deployed transceivers of proposed algorithm and benchmark 1 are approximative. The proposed algorithm performs similarly as benchmark 2 when the network gradually becomes congested. Therefore, the numbers of transceivers used by the two algorithms are approaching. Although benchmark 2 method utilizes slightly less number of transceivers, it suffers higher service blocking probability.

Fig. 3 demonstrates the network throughput of 1% blocking ratio as a function of PSD for the proposed algorithm and 2 benchmark methods. For all 3 algorithms, it can be observed that the system throughput raises as the PSD increases from 10 mW/THz to 19 mW/THz. But the capacity decreases gradually as the PSD continuously increases. It indicates that 19 mW/Thz is optimal PSD value for all the scenarios. Proposed

algorithm offer up to 7% and 26% more capacity compared to two benchmarks respectively when the network operates in optimal PSD.

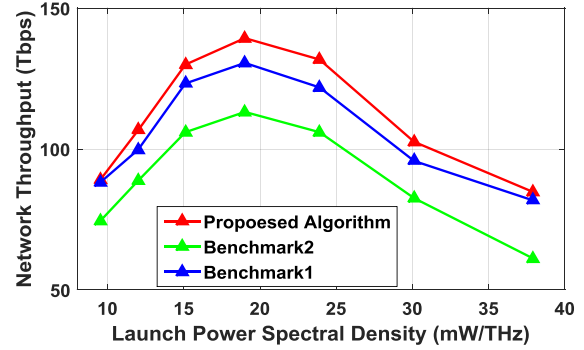


Fig. 3: Network throughput versus increasing PSD.

## Conclusion

In this paper, we proposed a traffic grooming enabled algorithm based on average link loading status. Through the numerical simulations, the proposed scheme outperforms two benchmark methods. We also show the tremendous number of transceivers saving over non-traffic grooming benchmark solution and significantly better service acceptance ratio over traffic grooming benchmark solution at the cost of utilizing only 6% more transceivers. The results verify the benefits of the proposed solution with different PSD values.

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